Chapter II.—GEOGRAPHICAL AND PHYSICAL CONDITIONS.

1. GEOGRAPHY.

The general geographical features of the region may be seen at a glance by reference to charts 223, 224, and 225[a]. Vineyard Sound has a length of from 15 to 17 nautical miles, depending upon the limits arbitrarily chosen,[b] and a width of from 3 to 6 nautical miles. Its main axis bears from northeast to southwest. The southeastern boundary is constituted by the island of Marthas Vineyard, the northwestern by the Elizabeth Islands and for a short space by the mainland of Cape Cod. At its eastern end Vineyard Sound passes imperceptibly into the far wider Nantucket Sound, while to the westward it opens freely to the Atlantic Ocean. It is connected with Buzzards Bay by a series of narrow straits, of which Woods Hole is a type. Through them the tidal currents are very swift. These straits separate the Elizabeth Islands from the mainland and from one another. There are no streams of any consequence emptying into either Vineyard Sound or Nantucket Sound.

Leaving out of consideration certain shoals and the zone immediately adjacent to the shore line, the depth throughout Vineyard Sound ranges between 6 and 18 fathoms, most soundings lying between 10 and 15 fathoms. There is in no sense a progressive deepening of the water as we pass toward the western end of the Sound, although some of the greatest depths (18 fathoms[c]) occur in the vicinity of Gay Head and Cuttyhunk. At least one sounding as great as this has, however, been made back of Middle Ground Shoal, and depths as great as 17 fathoms occur at more than one point in the eastern half of the Sound. As a rule, the 10-fathom line runs within a half mile from shore, though mention must be made of an elongated shoal reaching well toward the middle of the Sound and extending throughout about half its length. This is known at its eastern end as the Middle Ground, the opposite end being called Lucas Shoal. In the former portion the water may be no deeper than 4 feet or less in depth at mean low tide.

Buzzards Bay has a length of about 25 nautical miles, as measured from the railway station known as Buzzards Bay to the Hen and Chickens Shoal. Its main axis is nearly parallel to that of Vineyard Sound, from which it is separated throughout the lower half of its length by the Elizabeth Islands. Elsewhere it is bounded by the mainland of Massachusetts. At its northern end and along its entire western side the shore line of Buzzards Bay is very irregular, being indented by a considerable number of estuaries,

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[a] These and other geographic and hydrographic charts used in the present report are the work of Mr. W. F. Hill, formerly draftsman in the Bureau of Fisheries.

[b] The region explored during our dredgings extends a short distance into what would probably be commonly regarded as belonging to Nantucket Sound, though there is, of course, no definite line of division between the two.

[c] Our own soundings give 19½ fathoms at one point (*Fish Hawk* station 7683), while the greatest depth indicated on the Coast Survey chart for Vineyard Sound is 18 fathoms at mean low tide. Perhaps the phase of the tide is partly accountable for this difference; perhaps it rests upon an error of observation. The depth recorded by us for station 7682 (19 fathoms) is quite likely due to an error. Otherwise no serious discrepancies have been detected between the *Fish Hawk* soundings and those of the Coast Survey. In general our soundings (*Fish Hawk* and *Phalarope*), while not always taken with great care, are believed to be close enough approximations, especially when the variability in depth throughout the extent of the Bay and the Sound are considered.

which penetrate deeply into the mainland. Some of these, as will be shown later, furnish considerable quantities of fresh water at certain times of the year. The depth of Buzzards Bay beyond the "adlittoral" zone (see p. 179) ranges from 3 fathoms near its head to 18 or more fathoms at its mouth. About a mile west of Penikese Island occurs a deep hole only recently charted. Here a depth of 24 fathoms has been found, this being, so far as known, the deepest sounding obtainable within a distance of 10 miles or more from land. Throughout most of its extent, however, Buzzards Bay is much shallower than Vineyard Sound, and a depth of 10 fathoms is seldom or never encountered except near its lower end.

The conditions existing in Buzzards Bay and Vineyard Sound can not be understood without reference to the adjacent features of the coast and the ocean. The tidal currents, as well as the character of the water, are doubtless influenced by the proximity to the westward of Narragansett Bay and Long Island Sound. From the mouth of Vineyard Sound the Atlantic Ocean, throughout an arc of about 120°, extends for an indefinite distance uninterrupted either by land or by shoals. The depth, on the whole, increases very gradually, the "continental shelf" extending out to a distance of over 75 miles to the southward of Gay Head, where the 100-fathom line is encountered. Shortly thereafter an abrupt descent commences. South of Marthas Vineyard the 20-fathom line lies 10 miles or more off shore, and the distance increases as we pass to the westward. South of Narragansett Bay, however, it sends a long slender loop in a northeasterly direction toward the mouth of Vineyard Sound, reaching a point within about 6 miles of Gay Head.

To the east and southeast of Woods Hole the geographical conditions are peculiar, and are highly important in determining the nature of the fauna and flora on this part of the coast. The peninsula of Cape Cod, together with the two large islands to the southward, inclose a broad, shallow body of water—Nantucket Sound. This attains a high temperature during the summer months, and doubtless in large degree influences the temperature of Vineyard Sound, with which its waters mingle freely as a result of tidal currents (p. 36). It is possible, also, as has been held by certain writers, that Cape Cod, together with Nantucket and its associated shoals, constitute a barrier which deflects a well-defined cold ocean current away from the mainland of the continent. Whether or not this is true, it is an undoubted fact that the coastal water temperatures to the east and north of Cape Cod are much lower during the summer months than are those immediately to the south of it. The resulting faunal differences will be discussed elsewhere, and the temperature conditions will likewise be considered more fully in another place.

2. CHARACTER OF THE SHORES AND BOTTOMS.

The dominant feature of the shores and bottoms along this section of the coast is the glacial débris. Although the main outlines of the land topography of this region may be preglacial, as Shaler (1898) contends, there are extensive morainal deposits upon Nantucket, Marthas Vineyard, and the Elizabeth Islands, as well as on neighboring parts of the mainland. Indeed, a large part of the local shore line and sea bottom still consists of practically unaltered glacial boulders and gravel, which have been subjected for only a comparatively brief period to erosion and transportation by waves and currents. Even the Middle Ground in Vineyard Sound is regarded by Shaler as "a bit of submerged land topography," and not as the creation of currents acting upon shifting sands. Sandy beaches are common upon the ocean shores of Marthas Vineyard and Nantucket, where the surf is heavy and erosion is known to be progressing rapidly. Elsewhere within our region stones and gravel are a characteristic feature of the shore line. Commonly, this coarser material extends down the beach to low-tide mark or beyond, being succeeded by a gently sloping sand flat, more or less interspersed with scattered stones and boulders. In places where the shores are not too steep the stony belt gives place on its landward side to a sandy beach of varying breadth, or the littoral zonation may at times be even more complex. On the other hand, there are many tracts of shore where this phenomenon is not manifest at all, the entire shore and the adjacent sea bottom, so far as visible, being wholly stony. Mud, largely of organic origin, occurs in abundance in bays and inclosed waters which are not swept by tidal currents.

At certain points within our area preglacial formations have become exposed. As the most conspicuous instances of this we may cite the cliffs of colored clay at Gay Head and the outcroppings of granitic rock in the vicinity of New Bedford Harbor. These last represent a formation "which probably in large part constitutes the foundation rocks beneath the sea and under the islands which lie to the north of Marthas Vineyard." (Shaler, 1888, p. 323.) This formation is the probable source, according to Shaler, of the glacial bowlders of Marthas Vineyard. Passing reference may be made here to Shaler's hypothesis that Buzzards Bay and Vineyard Sound each represents the submerged valley of a former river. It does not lie within the province of this report, however, to consider the various problems relating to local geology.[a]

As regards bottom characters, Vineyard Sound and Buzzards Bay stand in striking contrast to one another. In the former, stones, gravel, and sand predominate; in the latter, mud. These differences are very readily explained. Vineyard Sound is constantly swept by strong tidal currents, which prevent the accumulation of fine deposits except in sheltered bays, such as Tarpaulin Cove and Menemsha Bight. Buzzards Bay, on the other hand, being open only at the lower end, is not subjected to such a thorough scouring by the tides (see p. 37), and here, therefore, large deposits of mud occur, as, indeed, they do at all points on the sea bottom off shore at depths which are beyond the influence of currents. Moreover, there open into Buzzards Bay a number of rather large estuaries, which doubtless furnish much of the material which becomes deposited as mud. It has been shown that silt so fine as to remain for a long period in suspension in fresh water is soon precipitated when mixed with sea water. (Allen, 1899, p. 380.) Thus it is evident that a considerable part of the suspended material from the brackish-water estuaries which empty into the northern and western parts of Buzzards Bay must settle to the bottom before it can be transported to any great distance.

One of the data recorded at each dredging station was the nature of the bottom so far as revealed by the sample brought up. The classification was a very rough one, and it must be freely confessed that it could have been greatly improved. The following were the principal ingredients recognized: (1) Sand; (2) gravel (referred to as "pebbles" when fine); (3) stones; (4) shells; (5) mud. These ingredients occurred singly or in almost any combination.

[a] The reader is referred to Shaler's two papers already cited.

Referring to the first three heads, it must be stated that the ordinary glacial drift of the region, like that which is distributed so widely elsewhere, consists of a mixture, in varying proportions, of sand, gravel, and stones. These three terms are not employed in the same definite sense as they are, for example, by E. J. Allen (1899). This writer restricts the word "sand" to mixtures of particles the coarsest of which will pass through a 1½ mm. sieve, the finest passing through a ½ mm. sieve, but not remaining in suspension for more than one minute in sea water. Under this main class he recognizes three subdivisions. "Gravel" (also subdivided into "fine," "medium," and "coarse") comprises aggregations of particles ranging from 1.5 mm. to 15 mm. in diameter. Any inorganic material coarser than this was listed by him as "stones." Our use of these terms, though far less precise than Allen's, we believe to correspond more nearly with common usage. In many cases our "sand" would probably comprise Allen's finer grade of "gravel," and our "gravel" would comprise much which he would term "stones." Thus stones which were frequently as large as an inch or more in diameter were considered as belonging to the "gravel."

The truth is that any such classification is arbitrary, and, unless actual measurement is employed, as has been done by Petersen and by Allen and Worth, these designations must be extremely ambiguous. Moreover, it is very doubtful whether an exact classification, such as the foregoing, would be of any service in the case of our local sea bottoms, which vary so much, even within the limits of a single dredge haul.[a] As will be pointed out later, the nature of the methods employed renders it possible to state with only a rough degree of approximation the extent of the correlation between the distribution of a given species and the character of the sea floor.

Another source of difficulty relates to the character of dredge employed at a given station. A canvas bag (p. 17) would retain all of the ingredients, and this could be washed and sifted and properly described. Such a small bag would frequently fill almost immediately, however, and thus fail to represent the entire course of the haul. During the earlier portion of the work the sample was commonly collected by an ordinary dredge net having a very close mesh at the bottom. It is obvious that if the mixture consisted of sand and gravel, much of the former might be lost during the reeling in of the dredge line, and that the sample might be listed as merely "gravel," whereas sand predominated at the outset. On the other hand, a sample in which sand predominated was doubtless at first often listed as "sand" in cases where careful washing would have revealed the presence of small proportions of gravel or shells. The beam trawl, having no cutting edge, and having a net with a wide-meshed bottom, would bring up merely the loose stones lying freely upon the surface. Thus the "stony" bottoms of the earlier records may in some cases have included a certain proportion of sand and fine gravel, though such cases are probably infrequent, since the beam trawl was commonly not used upon bottoms known to be stony. Where no stones appeared in the trawl net it was usually assumed, in the absence of data to the contrary, that the bottom was sandy. However, as already stated, a small dredge was generally used along with the beam trawl.

[a] An idea of the variability in the character of the bottom within comparatively narrow limits will be gained from considering the results of some of our supplementary dredgings, in the course of which over 100 of the original stations were repeated with a rather rough approach to accuracy. On comparing in each instance the earlier and later record for the same station it was found that in only 14 per cent of the cases were identical types of bottom recorded, while in only 33 per cent of the others were they substantially identical. In 47 per cent of the cases the ingredients recorded were partly the same, while in 6 per cent they were totally different. The later entries were as a rule fuller than the earlier ones, and this fact doubtless accounts for some of the differences, but they are likewise largely the result of real differences in the bottom passed over.

Large beds of nearly pure sand are without doubt common in Vineyard Sound, and are occasionally met with even in Buzzards Bay. Such are the great shoals of shifting sand of which Middle Ground in Vineyard Sound is a fair sample. These are veritable submarine deserts, often being almost devoid of life. Despite Shaler's assertion that in Vineyard Sound "the amount of sand at the disposition of the currents and waves is not large," we believe that such transportation is sufficiently active in some localities to be a determining factor in distribution. In the vicinity of Middle Ground and Lucas Shoal we have frequently observed the water to be rendered turbid by sand and fine shell fragments which had been brought up by the currents from a depth of several fathoms.

Beds of dead shells, accompanied by sand, gravel, or mud, occurred frequently, both in the Bay and in the Sound. These sometimes represented extinct mussel beds, though the shells of *Spisula solidissima*, *Arca transversa*, *Venus mercenaria*, *Venericardia borealis*, *Astarte castanea*, *Callocardia morrhuana*, *Anomia simplex*, *Pecten gibbus*, and other lamellibranchs sometimes occurred in great quantities. Among the gastropods, *Crepidula fornicata* is perhaps the only one which contributed materially to shell deposits, although the shells of many of the commoner species, occupied by hermit crabs, are frequently taken in great numbers.

Under "mud" is included a considerable diversity of material, differing in origin and in chemical composition, but agreeing in consistency and in general appearance. In a few cases the deposits represented upon the chart by the conventional shading for mud are fairly pure clay. Beds of this last material occur, as is well known, at Gay Head and the neighboring parts of Marthas Vineyard, and outcroppings of it are met with along the shores at various points within the region. In the course of the dredging clay was brought up in Vineyard Sound near the island of Cuttyhunk. Most of the mud, however, is composed in considerable part of organic matter. It is dark in color, and frequently has an offensive smell. It may be either sticky or semifluid or it may contain enough sand to alter the texture visibly. According as the mud or sand seemed to predominate in such a mixture, it was listed as "sandy mud" or "muddy sand." Sometimes such mixtures were called "sand and mud;" and in all probability the sand was at times overlooked, and the deposit was listed merely as "mud." Indeed, it is likely that almost any sample of mud, however pure in appearance, would be found upon careful sifting or decanting to contain a certain percentage of sand, and sometimes small amounts of fine gravel or shell fragments.

It had been our expectation to include in another chapter of this work the results of petrological and chemical analyses of the various bottom deposits, undertaken by Prof. Gilbert Van Ingen, of Princeton University. Thus far, however, Prof. Van Ingen has failed to complete his report upon these deposits, and its publication must therefore be deferred. The specimens upon which these analyses have been based were collected in 1905 during the third series of dredgings by the *Fish Hawk* in Vineyard Sound and in the course of some supplementary dredging, during the following summer, in Buzzards Bay. Satisfactory bottom samples from the earlier dredgings had not been preserved. In the present instance they were obtained exclusively by the use of a canvas bag, which prevented the washing out of the finer constituents. The larger ingredients, such as stones and large shells, were not, however, included in these samples preserved, so that such analyses, while highly valuable as studies in mineralogy, would not alone give a fair idea of the respective bottom areas considered as the habitats of living beings.

The chart showing bottom characters represents rather crudely the condition of the floor of Buzzards Bay and Vineyard Sound, certain conventional modes of shading being adopted to represent the chief ingredients. The circles having a composite shading are commonly divided into equal halves or thirds, as if the various constituents were present in equal amounts. This results from the imperfections, in this regard, of the records upon which this chart is based. In the plotting of these circles, likewise, it has been necessary to adjust the position of each to that of its neighbors, with the result that in certain cases the symbol is removed some distance from the bottom designated. This is particularly true of the adlittoral (*Phalarope* and *Blue Wing*) stations.

Excluding a more or less narrow adlittoral zone, the bottom area here portrayed divides itself into three main regions: [a]

(1) Vineyard Sound, from its eastern end to a transverse line of division passing at a level somewhere between Tarpaulin Cove and Robinsons Hole. Here the predominant feature is the presence of gravel and stones. This area, it is true, contains one extensive shoal of sand, the so-called Middle Ground, and many other sandy areas. In the bays mud likewise occurs.

(2) Vineyard Sound from the line above referred to to its western end. Here the bottom is predominantly sandy, though gravel, stones, and mud occur in places. The presence of shell beds does not, of course, exclude the occurrence of an underlying bottom of sand.

(3) Buzzards Bay as a whole. Here mud predominates, except close to the eastern shore, and at the extreme lower end. The latter might be regarded as an independent area, but it seems scarcely large enough to warrant this.

The inshore (adlittoral) dredgings reveal in many cases a distinctly different type of bottom from that of the adjacent deeper waters; and various restricted areas of one or another kind of bottom may be found almost anywhere.

Owing to the methods employed, it is evident that the correlation of bottom characters with the distribution of species can be indicated with only rough approximation. During a given haul the dredge passes over a considerable stretch of sea floor and may collect samples of several totally different sorts of material. Organisms may likewise be collected from all points in this path. To determine by such means the kind of bottom proper to every species encountered is obviously impossible. A species may appear in the records as coming from "sand," whereas it may have been scraped from the surface of large stones at any point during the haul. Only the broader correspondence between the larger areas in which certain types of bottom predominate, and the general distribution of the species in question, is commonly to be regarded as significant. Again, when certain organisms are listed from certain types of bottom, the inference must not always be drawn that such bottoms themselves constitute its true habitat. Thus encrusting Bryozoa, which occurs upon shells, or algæ, are frequently listed from bottoms of sand or even mud.

[a] These divisions do not correspond to those recognized in the botanical section of this report. Of the latter there are five.

3. CURRENTS AND TIDES.

The first currents which concern us are two of the great permanent streams which maintain the circulation of the ocean, namely, the Gulf Stream and the southwardly flowing Labrador Current. Off the Massachusetts coast, the Gulf Stream is first encountered at a distance of about 85 nautical miles south of Marthas Vineyard and Nantucket; that is, just beyond the edge of the continental shelf. Its distance from shore varies from year to year, and even during lesser periods. It has been shown by Libbey (1895) that the Gulf Stream, during this part of its course, at least, presents by no means a regular outline in crosssection, but exhibits, on its coastal side, a wall having very roughly the contour of an inverted S. Its lower boundary, which Libbey identifies approximately with the 50° (F.) curve, sends a projection coastward between the adjacent colder zone and the bottom, while at a higher level the cold stratum referred to projects seaward into the midst of the warmer water of the Gulf Stream. (See Libbey's fig. 1–21.) This brings about the result that throughout a narrow strip along the continental declivity the latter is bathed by warmer water than it would otherwise be exposed to, and consequently supports a different fauna.

A not wholly convincing illustration of the dependence of the fauna of this section of the ocean upon the chance relations of these temperature zones is offered by the case of the well-known tilefish, which suddenly disappeared from the edge of the continental platform for a period of about 10 years. (See Collins, 1884; Verrill, 1884; Libbey, 1895; Bumpus, 1899.) Its extermination was first revealed by the presence, during the spring of 1882, of enormous numbers of the dead fishes floating upon the surface of the sea throughout a belt parallel to the coast and about 170 miles in length. At the same time Verrill (1884, p. 656) reported the "scarcity or absence of many of the species, especially of Crustacea, that were taken in the two previous years, in essentially the same localities and depths in vast numbers—several thousand at a time." Verrill accounted for this wholesale destruction of life by the occurrence of a heavy storm, which he believed to have "forced outward the very cold water that, even in summer, occupies the wide area of shallower sea, in less than 60 fathoms, along the coast, and thus caused a sudden lowering of the temperature along this narrow, comparatively warm zone, where the tilefish and the Crustacea referred to were formerly found." Libbey has endeavored to correlate the reappearance of the tilefish, about 1892, with a change in the position of the 50° curve; and, indeed, the first successful search for the fish after the catastrophe of 1882 was suggested by the discovery of changed temperature conditions.

But the influence of the Gulf Stream extends much nearer to the coast than the edge of the continental shelf, and without doubt affects our local faunal conditions. The presence nearly every year in Vineyard Sound of considerable masses of the *Sargassum bacciferum*, with its attendant fauna, shows that strong southerly winds may drive the surface water of the Gulf Stream as far as the mainland of Massachusetts.[a] And, apart from these occasional and obvious effects, it is probable that the warm current exerts a constant influence upon the coastal waters of southern New England, the two undergoing a certain degree of intermingling as a result of winds and tides. Indirectly,

[a] The prevailing wind during the summer months blows from the southwest quadrant. From records kept for five years on the Vineyard Sound Lightship (Rathbun, 1887), southwesterly winds are found to be the most frequent ones during the months of April to September, inclusive. At Nantucket, also, according to the report of the Chief of the Weather Bureau for 1909–10, the prevailing direction of the wind from May to September, inclusive, is southwest.

also, through its influence upon the atmosphere, the Gulf Stream must have a very pronounced effect in tempering the climate of this section of the coast, and this without doubt reacts upon the local sea areas.

As regards the presence of a definite southward-flowing cold current on the New England coast, there seem to be decided differences of opinion. According to the prevailing view, the Polar or Labrador Current may be detected along practically the entire Atlantic coast of the United States. A concise statement of this view has been furnished us by the Navy Department:

> A cold current originating in high northern latitudes flows down past Labrador and Newfoundland, after which a portion trends away toward the southward over the Grand Banks, past Nova Scotia, and on southward in a narrowing belt as far even as the coast of Florida. From Sable Island to Florida its course is in general parallel to the Gulf Stream, near which it presents the frequent phenomenon of cold water welling up from below. In the shallower waters of the coast this colder current gives way to tidal influences which prevail to seaward over a wide area east of Nova Scotia, throughout the entire Gulf of Maine, and over Georges Bank and Nantucket Shoals.

Similar views are embodied in a number of different publications of the Hydrographic Office and Coast Survey and in certain Government charts. (E. g., Current Chart of the North Atlantic Ocean, No. 1308, pub. 1892.) They appear likewise in various popular accounts and atlases. (See Boguslawski, 1884, p. 269–272; Boguslawski and Krummel, 1887, p. 436, 437.) This assumption of a continuation of the Labrador Current along the southern shore of New England was made by Libbey, who thus interpreted the temperature relations which he observed there. Indeed, Libbey believed that the line between the two currents could often be seen from the deck of a vessel. (Libbey, 1891a, p. 236.) Various biologists also, including Packard and Verrill, have invoked the aid of this northern current in endeavoring to explain certain phenomena of geographical distribution. Verrill (1871, p. 258), indeed, believed that he found evidences of an offshoot of the Labrador Current extending for some distance into Long Island Sound.

According to another view of the case, the Labrador Current can not be traced farther south than Newfoundland, along the American coast, and has no connection with the "cold wall" or belt of cooler water lying between the Gulf Stream and the shores of the United States. It is held by Schott (1897, p. 204–208; see also Supan, 1903, p. 295) that such southward-flowing cold water as is found along the New England coast comes mainly from the Gulf of St. Lawrence; that the extent of this flow is but slight, and that the presence of the "cold wall" is largely a contrast phenomenon, due to the presence of the warmer Gulf Stream beyond.

Whether or not there occurs along the southern coast of New England a definite cold current of any considerable velocity, and, if so, whether this current is a continuation of the Labrador Stream, are matters of subordinate importance for our understanding of the biology of this region. The undisputed facts in the case seem to be that there is a belt of relatively cold water lying between the Gulf Stream and the New England shores, and that in summer this belt has a temperature very much lower than that of the waters immediately skirting the coast, particularly those of the partially inclosed bays and sounds, with whose fauna we have at present to deal. There is evidence, also, that north of Cape Cod this cold belt reaches the shores of the mainland itself and directly influences the littoral fauna; while south of Cape Cod it lies at some distance from the mainland, though its presence is felt upon the outlying shores of Marthas Vineyard and Nantucket. Referring to the temperature charts for the northwestern

Atlantic (charts 220, 221, 222), it will be seen that during the months of June to September, inclusive, the waters of Long Island Sound and those at the station just south of Buzzards Bay have a temperature several degrees higher than that of the first two stations to the eastward of these points. Farther yet to the eastward, however, the temperature again rapidly rises, owing to the presence of the Gulf Stream. The local relations will be discussed more fully in the next section of this chapter.

In addition to these great ocean streams, the local currents due to tides are very important in determining the fauna and flora of our waters. Tidal currents of sufficient velocity to be reckoned with by mariners occur at considerable distances offshore and, when deflected and concentrated by features of the coast line or by shoals, their velocity may be very great. In Woods Hole Passage, for example, they attain the speed of 8 miles per hour at spring tide. Such rapidly flowing currents, where the water is shallow and the bottom rocky, must result in a very high degree of oxygenation of the water. Moreover, a rapid current, of course, bears a more abundant food supply to those fixed or slow-moving organisms which depend for their food upon minute particles brought to them passively, or, as is the case with plants, upon gases or other substances in solution. Accordingly, we find beds of mussels and luxurious growths of anemones, ascidians, hydrozoa, bryozoa, and algæ in some of these tidal streams. On the other hand, tidal and other currents undoubtedly have a deleterious influence upon certain other organisms, which, through their agency, may become buried in sand or mud.

But the most widely prevailing effect of the tides locally is the continual mixing of the warmer (in summer), less dense, and relatively impure water of the coast line with the unlimited reservoir of cooler and purer water offshore. An idea of the magnitude of this process may be gained by considering the rate of tide flow in Vineyard Sound. This is as high as 2.6 knots per hour in the middle of the channel at the time of maximum velocity of the current. It is stated that "an object set adrift at the time of slack before flood will be carried 7 sea miles eastward before the reversal of the current, and an object set adrift at the time of slack before ebb will be carried 9 sea miles westward before the beginning of the flood stream."[a] Thus a certain part of the water at least travels a distance of one-half or more of the length of Vineyard Sound during a single phase of the tide. Owing to the retardation due to the friction of the shores and bottom, the mean sectional velocity would perhaps not exceed half the figures stated above. Even so, however, the water throughout the entire section would be displaced on the average to the extent of 3½ nautical miles during the flood phase and to the extent of 4½ miles during the ebb.

There would thus be a net westerly movement of the water amounting to about 1 knot during each complete tidal cycle, or about 2 knots in 24 hours. Were this the only factor concerned, it would thus require about eight days to completely replace the water of Vineyard Sound. In reality the ocean water brought in during the flood tide constantly mixes with that already present in the Sound, and this process of diffusion must result in a fairly rapid renewal of the latter, quite independently of the transfer of water resulting from the predominance of the westerly current. It seems likely, therefore, that a week would much more than suffice to bring about a practically complete change of water in Vineyard Sound. Obviously, the conditions are much less simple in reality

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[a] These data, though not the deductions which have been drawn from them, were furnished by the office of the Coast and Geodetic Survey. See also current diagram for Nantucket and Vineyard Sounds, in U. S. Coast Pilot, Atlantic Coast, pt. III, p. 152.

than is implied in such a computation, for the rate of renewal is very different in different parts of the Sound. The more central portion of the stream would enter to a much greater distance than that close to shore, while the waters contained in various depressions of the bottom (if we may judge from temperature considerations) are probably renewed at a comparatively slow rate.

In Buzzards Bay the change is in all probability much more slow, owing to the fact that this body of water communicates with the ocean at one end only, and that its mouth is very narrow in proportion to the total area of the Bay. Here there plainly can be no such continuous displacement in one direction as was found to occur in Vineyard Sound, and the renewal must be effected entirely through the mixture of waters resulting from the ebb and flow of the tide. The amplitude of the tides is, however, considerably greater in the Bay than in the Sound. Since the mean depth of the former is much less than that of the latter, a proportionally larger degree of change must result from this cause. The mean depth of Buzzards Bay, as computed from the 91 soundings indicated upon the chart contained in the Atlantic Coast Pilot, part III, is a little over 41 feet. The average rise and fall of the tide in Buzzards Bay is about 4 feet. Thus the amount of water brought in by the flood tide is equal to about one-tenth of the total volume already contained in the Bay. To what degree this ocean water mixes with that already present in the Bay, and, conversely, what proportion of the water which leaves the Bay on the ebb tide consists of that which entered on the previous flood, would be impossible to determine even approximately. Assuming that as much as one-half of this remains behind, which seems an extreme supposition, then the entire Bay would require 20 tides or 10 days to effect a complete renewal. On the whole, therefore, it seems likely that the average rate at which the water is renewed in Buzzards Bay is not over half that which obtains in Vineyard Sound.

It is obvious, however, that this renewal of water would take place at quite different rates in different parts of the Bay. Near the mouth the change is probably much more rapid than the above figures would imply, while at its head the renewal of water is probably far slower. Likewise the surface water is probably changed at a much more rapid rate than are the lower strata. It must be remembered, also, that it is not pure ocean water which enters either the Bay or the Sound, but coastal water, which has been contaminated during previous ebb tides. Nevertheless, even such crude estimates may be of service in showing the relative stagnancy of the two bodies of water under consideration.

A feature of great importance in determining the character of the local littoral fauna and flora is the slight amplitude of the tides throughout the entire region. A table will best illustrate the amplitude of the mean, spring, and neap tides at 11 representative points.

	Mean.	Spring.	Neap.		Mean.	Spring.	Neap.
	Feet.	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
Wareham	4.1	5.1	3.0	Tarpaulin Cove	2.3	2.8	1.7
New Bedford	4.2	5.2	3.1	Vineyard Haven	1.7	2.1	1.2
Woods Hole (Bay side)	4.1	5.0	3.0	Woods Hole (Sound side)	1.7	2.1	1.2
Mouth of Bay (Westport)	3.1	3.8	2.3	Edgartown	2.0	2.4	1.5
Cuttyhunk	3.5	4.3	2.6	Nantucket Harbor	3.1	3.8	2.3
Gay Head	3.0	3.7	2.2				

The resulting narrowness of the littoral (intertidal) zone is a characteristic feature of the region, and stands in decided contrast to the conditions encountered on the Maine coast, where the average tidal range is not less than 10 feet.

4. TEMPERATURE.

The surface and bottom temperatures were recorded for each of the regular dredging stations of the *Fish Hawk* and were entered in the original records for these. It became evident, however, that the methods then employed were not sufficiently accurate for purposes of careful comparison; likewise that the temperature determinations should be taken as nearly simultaneously as possible throughout the entire area under consideration. Accordingly, new observations were made at four different seasons of the year, with standardized instruments and in accordance with more precise methods. Density determinations were made at the same time as those upon temperature, but a discussion of these will be deferred till the following section.

The methods pursued in making the temperature observations were as follows: Certain stations were selected which were believed to be representative of all sorts of conditions as to geographical position, depth, tidal influences, etc. These were commonly selected from among the regular dredging stations plotted upon the distribution charts, but they were not located by the vessel with any close approach to accuracy. In a few cases, however, other points were chosen, so that it was thought best to give a new set of numbers, or rather letters, to the temperature stations. They ranged from A to Y in the Sound and from A to V in the Bay.[a] (See chart 211.) In taking the August series of temperatures the *Fish Hawk* was employed; in November and June the *Phalarope* was used; in March the *Blue Wing*. The bottom temperatures were obtained with Negretti-Zambra thermometers, provided with the Tanner inverting case (Tanner, 1884, p. 26); and the instrument was in all cases left at the bottom for a period of 10 minutes. Our own and previous tests (see Kidder, 1887, p. 203) have shown that reliable results can not be obtained in less time. The thermometer was then upset by a "messenger," rendering impossible any further change in the column of mercury, except the slight expansion or contraction of the thread itself, which could be allowed for whenever the water and air temperature differed sufficiently. The surface temperature was taken by means of an ordinary thermometer of the Queen or Tagliabue make, having a long scale. Surface water was drawn in a dip bucket and kept in the shade while the thermometer was in use. When air and water temperature differed much, the pail of water was changed at least once before the final reading was made. The air temperature was likewise recorded, though this was far from exact, owing to the artificial sources of heat necessarily present on a steam vessel.

August series.—The first series of temperature determinations was made between August 14 and 29, 1907. Twenty-five observations in Vineyard Sound were made on August 14, 15, and 16. The order followed was such that stations scattered throughout nearly the whole length of the Sound were visited on the same day. Thus, differences due to locality would not be confused with differences due to meteorological changes. Buzzards Bay was then covered on August 19 and 20, most of the stations being reached on the first day. Certain stations in Vineyard Sound were also revisited

[a] Not all of these stations were included in every series of observations, while the greater number of the Bay stations were omitted from the March series.

on August 20, as likewise on August 22; and stations in both Vineyard Sound and Buzzards Bay were visited for a second, third, and even fourth time on August 28 and 29. Thus, while it is not possible to present simultaneous readings throughout all the waters under consideration, the most extreme points were reached within a limit of five days (August 14–19); and such supplementary determinations were made as to eliminate confusion of results by seasonal change. A consideration of these supplementary temperature determinations, 41 in number, shows that, although they were made after an average interval of nine days, the mean difference (irrespective of sign) between the first and the later determination was 1.8° F. It will be noted also that in many cases the later temperature was higher, instead of lower, though, on the average, it was found to be about $\frac{3}{10}$ degree lower. Moreover, a consideration of the chart (No. 219) representing the mean annual temperature curves for the Woods Hole station shows that the variation in water temperature at the latter point during the entire period of the present observations (August 14–29) is, in this five-year average, but a trifle over 1° F. The variations within the limits of a single day, due to tidal influences, are doubtless more serious sources of error, at least for surface temperatures; but it was, of course, impossible to eliminate these.

TABLE 1.—TEMPERATURE AND DENSITY: VINEYARD SOUND, AUGUST, 1907.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15° C.).	Bottom temperature.	Bottom density (at 15° C.).
A	Aug. 16	9½	67.3	68.6	1.0239	68.8	1.0239
B	..do....	4½	67.7	68.3	1.0238	68.1	1.0239
C	..do....	7	68.3	67.6	1.0241	67.4	1.0237
D	..do....	11¼	67.7	66.8	1.0237	66.3	1.0242
E	Aug. 14	5	....	....	1.0238	69.3	1.0241
F	..do....	10½	66.3	....	1.0239	68.5	1.0237
G	Aug. 15	10	67.3	67.3	1.0241	66.9	1.0241
G (repeated)	Aug. 22	11	67.0	66.4	1.0237	66.3	1.0237
H	Aug. 16	9½	67.8	65.8	1.0242	65.3	1.0240
I	Aug. 14	9½	66.7	....	1.0235	67.5	1.0239
I (repeated)	Aug. 22	10¼	67.8	67.3	1.0234	65.5	1.0236
J	Aug. 15	10	68.3	67.3	1.0240	67.4	1.0239
J (repeated)	Aug. 22	10½	67.3	64.6	1.0236	63.4	1.0236
K	Aug. 16	9	68.3	66.3	1.0239	65.3	1.0239
L	Aug. 14	12¾	67.8	66.8	1.0240	65.5	1.0240
L (repeated)	Aug. 22	16	67.6	65.6	1.0237	62.4	1.0236
M	Aug. 15	6½	70.3	62.8	1.0243	61.4	1.0243
N	..do....	12¾	69.3	65.3	1.0241	61.1	1.0239
N (repeated)	Aug. 22	....	68.3	64.3	1.0238	60.3	1.0237
O	Aug. 14	9	67.1	65.8	1.0238	63.5	1.0241
P	Aug. 16	10	66.8	64.8	1.0239	60.9	1.0241
P (repeated)	Aug. 22	12¾	66.2	61.9	1.0237	58.2	1.0237
P (repeated)	Aug. 28	13½	70.3	63.7	1.0235	61.4	1.0238
Q	Aug. 15	8½	69.8	63.8	1.0243	59.3	1.0243
R	Aug. 14	10	69.1	69.3	1.0238	61.4	1.0239
S	..do....	10	68.7	62.8	1.0237	58.6	1.0241
T	Aug. 16	14½	64.5	63.0	1.0240	58.8	1.0239
U	..do....	11¾	64.9	62.4	1.0242	59.2	1.0236
U (repeated)	Aug. 22	11	71.8	63.3	1.0237	61.7	1.0237
U (repeated)	Aug. 28	11½	70.3	62.3	1.0235	61.2	1.0234
V	Aug. 16	10½	64.2	63.1	1.0241	60.1	1.0241

TABLE 1.—TEMPERATURE AND DENSITY: VINEYARD SOUND, AUGUST, 1907—Continued.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
V (repeated)	Aug. 20	9¾	69.7	64.3	1.0233	61.2	1.0236
V (repeated)	Aug. 28	7½	68.3	64.3	1.0240	60.2	1.0238
V (repeated)	Aug. 29	9¾	64.3	63.1	1.0240	58.2	1.0239
W	Aug. 16	17¾	64.3	60.3	1.0241	55.0	1.0241
W (repeated)	Aug. 20	17¾	72.3	64.3	1.0234	59.0	1.0237
W (repeated)	Aug. 28	17	71.8	63.9	1.0239	59.9	1.0241
W (repeated)	Aug. 29	14½	63.8	61.5	1.0240	57.2	1.0242
X	Aug. 16	12½	64.6	63.8	1.0241	57.2	1.0241
X (repeated)	Aug. 28	16¾	69.3	62.5	1.0234	53.2	1.0239
Y	Aug. 16	8	63.8	63.3	1.0240	61.3	1.0239
Mean			67.68	64.70	1.02385	62.28	1.02389

TABLE 2.—TEMPERATURE AND DENSITY: BUZZARDS BAY, AUGUST, 1907.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
A	Aug. 19	3½	65.1	71.3	1.0226	71.3	1.0224
B	...do.....	3½	66.3	71.5	1.0229	71.0	1.0231
C	...do.....	5	64.3	70.3	1.0229	70.7	1.0232
D	...do.....	4	66.3	71.1	1.0233	70.2	1.0234
E	...do.....	5¼	67.3	70.3	1.0235	70.4	1.0234
F	...do.....	5½	62.8	69.5	1.0234	69.3	1.0235
G	...do.....	5¼	71.3	69.8	1.0236	68.3	1.0238
H	...do.....	9½	69.9	70.5	1.0234	66.0	1.0236
I	Aug. 20	6¾	66.5	69.3	1.0240	68.4	1.0235
J	Aug. 19	5	69.5	69.8	1.0237	68.3	1.0236
K	...do.....	8	66.3	69.8	1.0234	65.0	1.0234
L	Aug. 20	9	66.8	67.6	1.0232	64.6	1.0236
L (repeated)	Aug. 29	9½	65.2	65.2	1.0237	64.3	1.0238
M	Aug. 20	7½	67.9	68.8	1.0233	67.6	1.0237
N	...do.....	6¾	67.9	66.9	1.0235	65.3	1.0236
O	Aug. 19	7	66.6	67.8	1.0237	67.1	1.0236
P	Aug. 20	10	67.8	66.8	1.0234	64.2	1.0236
P (repeated)	Aug. 29	8	65.3	65.0	1.0235	64.3	1.0237
Q	Aug. 19	8½	66.1	67.3	1.0235	64.1	1.0235
R	Aug. 20	6¾	71.3	67.3	1.0235	66.6	1.0234
R (repeated)	Aug. 29	6¼	66.5	65.4	1.0235	64.7	1.0237
S	Aug. 20	12	74.8	67.8	1.0233	63.2	1.0236
T	...do.....	6¾	72.4	65.8	1.0233	63.2	1.0233
U	...do.....	9½	68.9	66.9	1.0236	64.3	1.0233
U (repeated)	Aug. 29	10	64.7	64.8	1.0238	64.0	1.0239
V	Aug. 20	12¾	72.3	64.8	1.0234	60.2	1.0236
V (repeated)	Aug. 29	9	64.1	62.7	1.0241	60.6	1.0237
Mean			67.56	67.93	1.02344	66.19	1.02350

Tables 1 and 2 show the temperature[a] and density conditions encountered during the August observations. Chart 211 represents the surface and bottom temperatures for each station, the figure used being in each case the earliest one taken. The following generalized statements may be made regarding these figures:

(1) The greatest extremes of temperature recorded are 71.5° and 55.0°, giving a range of 16.5° within the limits of the region.

(2) The surface temperatures average 2.21° higher than the bottom temperatures, the differences increasing as we pass toward the western end of Vineyard Sound and the lower end of Buzzards Bay. The mean figures (based upon all the figures of the tables) are surface 66.04°, and bottom 63.83°.

(3) Buzzards Bay contains warmer water than Vineyard Sound, the mean figures being 67.93° (surface) and 66.19° (bottom) for the Bay, and 64.70° (surface) and 62.28° (bottom) for the Sound.

(4) In both Vineyard Sound and Buzzards Bay, both at the surface and the bottom, there is a steady decrease in temperature as we pass from northeast to southwest; i. e., toward the open ocean.

In Buzzards Bay the maximum surface temperature (71.5°) was found near the head, while the minimum (64.8°) occurred off Cuttyhunk. The maximum bottom temperature also occurred at the head of the Bay, where surface and bottom waters were practically of equal warmth. A minimum of 60.2° was found off Cuttyhunk, just at the mouth of the Bay.

[a] We have very reluctantly decided to employ the Fahrenheit scale in the present work, for the following reasons: Our instruments, and practically all those in use by the Bureau of Fisheries, are graduated in this scale. Moreover, in past American hydrographic work temperatures have usually, if not always, been expressed in Fahrenheit degrees. We should, however, have employed the centigrade scale, despite the foregoing considerations, were it not for the fact that our temperature charts were drawn before due consideration was given to this matter; and it does not seem worth while to change them now, particularly as plates have already been prepared from some of them. For the convenience of those who are more familiar with the centigrade scale we append a conversion table:

TABLE FOR CONVERSION OF FAHRENHEIT TO CENTIGRADE DEGREES.

Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.
°	°	°	°	°	°	°	°	°	°
+80	+26.67	+69	+20.56	+58	+14.44	+47	+8.33	+37	+2.78
79	26.11	68	20.00	57	13.89	46	7.78	36	2.22
78	25.56	67	19.44	56	13.33	45	7.22	35	1.67
77	25.00	66	18.89	55	12.78	44	6.67	34	1.11
76	24.44	65	18.33	54	12.22	43	6.11	33	0.56
75	23.89	64	17.78	53	11.67	42	5.56	32	0.00
74	23.33	63	17.22	52	11.11	41	5.00	31	−0.56
73	22.78	62	16.67	51	10.56	40	4.44	30	−1.11
72	22.22	61	16.11	50	10.00	39	3.89	29	−1.67
71	21.67	60	15.56	49	9.44	38	3.33	28	−2.22
70	21.11	59	15.00	48	8.89				

In Vineyard Sound, the maximum surface temperature (69.3°) occurred near Nashawena Island, but such a temperature was quite exceptional in this portion of the Sound, as reference to the chart will show at a glance. With this exception, the highest temperatures are at the eastern end. At one station just beyond the western limits of Vineyard Sound (W) the surface and bottom figures were 60.3° and 55.0°, respectively. A rather abrupt fall in temperature is encountered in passing southwestward through the Sound when we reach the line passing from Robinson Hole to Kopeecon Point. The mean bottom temperatures for the portions of the Sound lying above and below this line are 67.35° and 60 24°, respectively (based upon chart figures only). As we shall find later, this lower temperature of the outer portion of the Sound is correlated with important differences in the bottom fauna. In Buzzards Bay the lowering of temperature toward the mouth is less abrupt, and water colder than 64° occurs only near the extreme end. The water appears to be at no point as cold as it is on the other side of the Elizabeth Islands.

TABLE 3.—TEMPERATURE AND DENSITY: VINEYARD SOUND, NOVEMBER, 1907.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
C	Nov. 12	8	39.0	50.2	1.0240	51.1	1.0242
D [a]	Nov. 11	11½	47.0	51.4	1.0237	51.6	1.0241
E	...do....	6	46.0	51.2	1.0238	51.4	1.0241
F	...do....	15	48.0	51.7	1.0238	51.4	1.0238
G	Nov. 12	10	40.0	49.7	1.0240	51.5	1.0241
G (repeated)	Nov. 15	11½	37.5	49.7	1.0240	50.3	1.0240
H	Nov. 12	7	39.0	50.7	1.0242	50.8	1.0242
I	Nov. 11	12	49.0	51.2	1.0238	51.4	1.0238
J	Nov. 12	10	39.5	51.1	1.0242	51.5	1.0241
K	...do....	13	40.5	50.6	1.0240	....	1.0241
L	Nov. 11	5	49.0	51.2	1.0238	51.4	1.0238
M	Nov. 12	7	40.5	51.1	1.0240	51.8	1.0240
M (repeated)	Nov. 15	7	39.0	49.7	1.0240	50.5	1.0240
N	Nov. 12	11½	39.0	51.1	1.0241	51.5	1.0241
O	Nov. 11	8	49.0	51.2	1.0238	50.9	1.0238
P	Nov. 12	12?	42.0	51.2	1.0241	52.0	1.0241
Q	...do....	8¾	41.0	50.7	1.0242	50.5	1.0240
S	Nov. 11	8	49.0	51.7	1.0238	51.1	1.0241
T	Nov. 12	14	42.0	51.7	1.0242	52.0	1.0241
U	...do....	10½	41.0	50.7	1.0241	51.9	1.0243
V	...do....	8	43.0	51.2	1.0241	51.9	1.0238
W	...do....	18	45.0	51.2	1.0243	52.0	1.0241
W (repeated)	Nov. 15	17½	40.0	50.1	1.0240	51.6	1.0241
X	Nov. 12	11½	39.5	51.2	1.0241	52.5	1.0244
Y	...do....	8½	41.5	50.9	1.0241	52.0	1.0242
Mean	....	....	42.64	50.90	1.02401	51.44	1.02406

TABLE 4.—TEMPERATURE AND DENSITY: BUZZARDS BAY, NOVEMBER, 1907.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
A	Nov. 13	3	35.0	46.3	1.0214	49.8	1.0220
B	...do....	2½	37.0	47.7	1.0228	49.4	1.0229
C	...do....	6	34.0	48.2	1.0228	50.1	1.0229
D	...do....	4½	43.0	48.2	1.0230	49.5	1.0230
E	...do....	6½	36.0	47.3	1.0226	50.0	1.0228
F	...do....	5½	35.0	48.5	1.0231	49.1	1.0232
G	...do....	5	39.0	48.7	1.0236	49.3	1.0236
H	...do....	8½	41.0	48.7	1.0237	49.8	1.0237
I	...do....	6	33.0	49.2	1.0235	49.8	1.0238
J	...do....	5	41.5	48.2	1.0234	48.9	1.0233
K	...do....	7	42.0	49.7	1.0237	50.5	1.0237
L	...do....	8½	43.0	49.5	1.0237	50.1	1.0237
M	Nov. 15	6	38.0	47.2	1.0238	47.5	1.0237
N	...do....	6½	35.5	48.0	1.0238	48.5	1.0239
O	...do....	5	35.5	48.5	1.0238	48.8	1.0238
P	...do....	8	36.0	48.6	1.0239	50.0	1.0240
Q	...do....	5½	36.0	48.7	1.0238	49.1	1.0239
R	...do....	6½	39.0	47.9	1.0236	49.1	1.0236
S	...do....	15	40.0	49.7	1.0237	50.5	1.0237
T	...do....	6½	39.0	49.7	1.0240	50.1	1.0240
U	...do....	7	43.0	48.7	1.0236	49.0	1.0236
V	...do....	17	40.0	49.7	1.0240	50.4	1.0240
Mean	....	....	38.25	48.50	1.02342	49.51	1.02349

November.—Temperature and density conditions at the middle of November, 1907, are shown in tables 3 and 4, the temperature conditions being shown on chart 212. When compared with the conditions during August, the chief facts to be noted are:

(1) The great reduction in water temperature naturally resulting from the approach of winter. The mean of all the figures is 50.14° as against 64.91° during the August observations.

(2) The comparative uniformity of all the figures, the extremes being 46.3° and 52.5°, showing a range of 6.2°, in place of a range of 16.5° as in August.

(3) The exact reversal of the differences found in August. Here the surface temperatures are somewhat *lower* than the bottom ones (average=49.78° and 50.47° respectively); the Bay is *colder* than the Sound (average=49.00° and 51.16°); and we meet with slightly *higher* temperatures as we pass toward the open ocean. This last tendency is not very evident in Vineyard Sound, but is quite marked in Buzzards Bay. All these differences are, of course, quite intelligible. At this time of the year the air temperature has become much colder than that of the water. It is natural, therefore, that the surface of the sea should cool more rapidly than the bottom, and that the shallower, more sheltered waters should cool more rapidly than the open ocean.

TABLE 5.—TEMPERATURE AND DENSITY, VINEYARD SOUND, MARCH, 1908.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
E	Mar. 20	5½	31.5	36.9	1.0236	36.8	1.0233
I	...do....	13	29.5	36.2	1.0232	37.6	1.0234
I (repeated)	Mar. 21	11	33.0	36.4	1.0235	36.5	1.0235
J	Mar. 20	11½	28.5	36.3	1.0233	36.3	1.0235
K	...do....	8	32.5	36.9	1.0237	36.7	1.0237
O	...do....	7	30.0	36.3	1.0232	36.2	1.0233
P	...do....	14	30.0	37.0	1.0238	36.6	1.0238
Q	...do....	10½	32.0	37.1	1.0237	36.6	1.0240
S	...do....	7	31.0	36.6	1.0236	36.5	1.0236
U	...do....	8	31.5	36.8	1.0238	36.6	1.0239
V	...do....	5	28.0	36.5	....	36.6	....
W	...do....	18	33.0	36.7	1.0238	37.4	1.0238
Mean	....	....	30.87	36.64	1.02356	36.70	1.02361

TABLE 6.—TEMPERATURE AND DENSITY, BUZZARDS BAY, MARCH, 1908.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
A	Mar. 21	2½	28.0	37.1	1.0212	37.6	1.0224
D	...do....	4	30.5	37.4	1.0222	36.6	1.0225
E	...do....	5½	28.0	36.8	1.0222	37.1	1.0234
F	...do....	4½	29.0	36.2	1.0226	36.1	1.0227
H	...do....	9	31.0	37.0	1.0226	36.5	1.0239
L	...do....	8½	30.0	36.7	1.0229	36.3	1.0234
Mean	....	....	29.41	36.86	1.02228	36.70	1.02305

March.—Another set of determinations was made on March 20 and 21, 1908 (tables 5 and 6; chart 213). Owing to the inclemency of the weather and to the fact that only the *Blue Wing* was available for the work, a smaller number of soundings was made at this time, and indeed the lower part of Buzzards Bay was entirely neglected. The results are none the less interesting. The mean for the entire set of 36 determinations (including both surface and bottom) was 36.71°. A high degree of uniformity was manifest throughout the entire region, for the most extreme temperatures recorded were 36.1° and 37.6°, while the average deviation (i. e., the average departure from the average) was only 0.32°. Moreover, such slight differences as did occur seemed to bear no definite relation to locality.

TABLE 7.—TEMPERATURE AND DENSITY, VINEYARD SOUND, JUNE, 1908.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
E	June 5	5	56	58.4	1.0233	58.4	....
H	...do....	7½	56	57.5	1.0234	57.4	1.0234
I	...do....	12	63	58.0	1.0233	57.7	1.0231
J	...do....	11	59	57.4	1.0234	58.3	1.0234
K	...do....	11½	57	57.4	1.0233	56.7	1.0234
O	...do....	8	59	57.2	1.0234	56.5	1.0233
P	...do....	13	59	56.3	1.0234	56.0	1.0235
Q	...do....	9	59	56.3	1.0233	55.4	1.0232
S	...do....	9	59	56.8	1.0233	55.8	1.0235
U	...do....	9	59	54.3	1.0234	49.8	1.0234
W	...do....	18	57	55.3	1.0233	53.3	1.0233
X	...do....	10	59	55.8	1.0243	47.9	1.0234
Y	...do....	9	60	54.6	1.0234	53.0	1.0234
Mean	....	....	58.61	56.56	1.02342	55.09	1.02336

TABLE 8.—TEMPERATURE AND DENSITY, BUZZARDS BAY, JUNE, 1908.

Temperature station.	Date.	Depth in fathoms.	Air temperature.	Surface temperature.	Surface density (at 15°C.).	Bottom temperature.	Bottom density (at 15°C.).
A	June 6	4	60	64.0	1.0224	64.4	1.0223
D	...do....	5	59	63.3	1.0223	62.8	1.0222
E	...do....	6¾	64	62.2	1.0227	61.6	1.0227
F	...do....	4¾	64	61.8	1.0227	60.3	1.0227
H	...do....	8	61	59.5	1.0233	59.1	1.0229
I	...do....	7½	56	56.1	1.0233	55.1	1.0234
J	...do....	5	57	61.4	1.0229	60.8	1.0229
K	...do....	8	59	59.7	1.0232	58.7	1.0231
L	...do....	9	55	57.8	1.0232	59.0	1.0234
O	...do....	5	56	61.3	1.0230	59.8	1.0232
P	...do....	12½	58	59.3	1.0232	57.6	1.0233
Q	...do....	6½	55	58.3	1.0235	57.9	1.0231
S	...do....	12½	57	58.3	1.0232	56.7	1.0232
Mean	....	....	58.53	60.23	1.02299	59.52	1.02295

June.—On June 5 and 6, 1908, surface and bottom temperatures were determined at 26 stations in Vineyard Sound and Buzzards Bay (tables 7 and 8; chart 214). The mean of all these 52 figures is 57.85° F., or 7.06° lower than the mean for the August observations. The relations which were found to obtain during August are, however, manifested with equal clearness in the June series, the figures being:

Maximum	64.40
Minimum	47.90
Mean for Buzzards Bay	59.88
Mean for Vineyard Sound	55.83
Mean for surface	58.39
Mean for bottom	57.31

It is likewise plain that the temperatures decline noticeably as we pass toward the open ocean, the maximum temperature being found at the head of Buzzards Bay, the minimum at the mouth of Vineyard Sound. There was, however, at the time of the June observations, no abrupt fall of temperature beyond Robinsons Hole.

Annual temperature cycle.—Before discussing the probable significance of these observations upon the waters of Vineyard Sound and Buzzards Bay, mention must be made of the annual temperature cycle at Woods Hole.

TABLE 9.—AIR TEMPERATURE AT NOON: WOODS HOLE STATION.

Years.	January.			February.			March.			April.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	46	12	30.3	42	21	30.7	53	29	42.7	62	40	49.4
1903	46	10	32.5	52	10	34.6	55	33	44.9	65	36	50.3
1904	45	2	26.3	45	8	26.6	50	21	37.1	58	36	45.4
1905	47	14	29.1	41	12	27.0	54	24	37.9	57	37	47.7
1906	53	18	37.0	47	11	33.2	51	24	35.3	59	38	48.9
Five years	53	2	31.03	52	8	30.39	55	21	39.58	65	36	48.33

Years.	May.			June.			July.			August.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	66	49	57.6	71	58	65.9	80	65	71.4	78	64	71.9
1903	76	46	60.7	71	51	63.1	79	64	72.4	76	57	70.1
1904	68	54	60.5	76	54	66.1	83	68	74.0	79	65	72.4
1905	69	50	58.4	78	48	66.4	82	63	74.0	80	60	70.4
1906	67	45	58.9	81	55	68.5	80	65	70.0	82	67	75.0
Five years	76	45	59.21	81	48	66.02	83	63	72.35	82	57	71.95

Years.	September.			October.			November.			December.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	75	61	67.9	68	41	57.7	59	38	50 7	47	2	33.6
1903	78	54	67.6	68	40	57.8	60	25	43.6	50	16	32.5
1904	74	48	65.8	69	38	54.9	54	27	42.1	47	15	30.7
1905	71	51	66.1	69	45	57.7	59	28	44.9	55	25	39.0
1906	75.5	58	67.7	70	49	58.9	57	33	45.1	48	9	33.4
Five years	78	48	67.01	70	38	57.39	60	25	45.29	55	2	33.82

TABLE 10.—WATER TEMPERATURE AT NOON, WOODS HOLE STATION.

Years.	January.			February.			March.			April.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	34.5	29.5	31.7	31.5	[a]28.0	29.3	42.5	32.5	36.6	52.0	41.5	45.8
1903	36.5	29.5	33.0	35.0	30.0	32.4	44.0	34.0	39.6	50.5	44.0	46.6
1904	32.0	[a]28.0	29.5	29.5	28.5	29.1	39.0	29.5	33.8	45.5	36.5	41.3
1905	35.0	29.5	31.0	30.0	29.0	29.5	39.5	29.5	32.9	48.0	39.5	42.9
1906	39.5	33.5	36.5	37.0	33.0	34.7	38.0	32.5	35.2	48.0	37.0	42.7
Five years	39.5	[a]28.0	32.33	37.0	[a]28.0	31.00	44.0	29.5	35.64	52.0	36.5	43.90

Years.	May.			June.			July.			August.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	59.0	51.0	54.6	65.0	58.5	62.9	69.0	64.0	66.7	71.0	68.0	69.3
1903	61.0	50.0	59.0	62.5	59.0	61.3	70.5	63.0	67.9	69.5	63.0	67.7
1904	61.5	46.5	54.1	69.0	58.5	62.8	73.0	67.0	69.8	72.0	69.0	70.2
1905	59.0	47.0	52.8	66.5	57.5	62.0	74.0	66.0	70.4	73.0	67.5	70.0
1906	58.5	48.5	54.1	68.5	58.5	63.2	73.0	67.0	69.3	74.5	69.5	71.4
Five years	61.5	46.5	54.92	69.0	57.5	62.42	74.0	63.0	68.83	74.5	63.0	69.74

Years.	September.			October.			November.			December.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1902	70.0	65.0	67.5	65.0	54.0	60.5	55.0	47.0	52.0	47.5	35.0	38.9
1903	69.0	63.5	66.6	64.0	51.5	59.2	53.5	38.5	47.9	40.0	32.0	36.6
1904	70.0	64.0	67.0	63.0	51.5	57.6	52.0	40.0	46.3	41.0	31.5	34.4
1905	69.0	63.0	66.4	64.0	54.0	59.6	54.5	44.0	48.2	44.5	38.0	40.0
1906	71.0	66.0	68.5	65.0	56.5	60.3	54.0	42.5	47.0	42.5	33.5	36.3
Five years	71.0	63.0	67.20	65.0	51.5	59.44	55.0	38.5	48.28	47.5	31.5	37.23

[a] Based doubtless upon an inexact observation, since this temperature is below the freezing point of sea water.

Curves showing seasonal variations in the air and water temperatures at the Woods Hole station for five years are presented on chart 219. These curves are based upon the noon temperatures contained in the station records from 1902 to 1906, inclusive.[b] The ordinate for each day is the mean of the five years' figures for that day. Such curves do not, of course, exhibit the extreme conditions, since maximum and minimum figures are neutralized in the process of averaging. The water temperatures are naturally those which chiefly concern us at present. It will be seen that the highest point in the curve showing these is at August 12, where the mean temperature is slightly over 71°. Reference to table 10 shows that the maximum temperature for August (and for the year) recorded during these five years is 74.5°. The lowest point in the curve is on February 19, where a mean temperature of 30° is almost reached. The minimum for the entire

[b] Cf. Edwards in First Report U. S. Fish Commission, with which these figures agree fairly closely.

period is about 28.5° F.,[a] which is the freezing point of sea water. This temperature is perhaps reached at one time or another nearly every winter.

An analysis of this curve reveals several other facts worthy of mention. (We omit as irrelevant the interesting relations between the curves for air and for water.) There are two comparatively level sections having a duration of about two months each, occurring in midwinter and midsummer, respectively. During each of these periods, the range of temperature is only about 3 degrees. The remainder of the year is made up of the long vernal ascent, and the somewhat more abrupt autumnal decline. During 131 days, or rather more than a third of the entire year (June 3 to Oct. 12), the temperature remains above 60°; from May 5 to November 8, the temperature exceeds 50°; while from April 3 to December 5, the curve is above the 40° line. On the other hand, from December 26 to March 14, the temperature of 35° is not exceeded.

The water here employed was that drawn from the surface at the local pier, close to the buildings of the station. This water rapidly changes with the tides which sweep through Woods Hole Passage, and therefore is not liable to the extreme fluctuations found in more inclosed areas. The figures doubtless represent fairly well the surface (and likewise the bottom) temperature of Woods Hole Harbor and of the adjacent shallower parts of Buzzards Bay and Vineyard Sound. The mean water temperature for this entire period of five years was 51.01° F.; the mean air temperature for the same period was 51.98°. Since these figures are based upon temperatures taken at noon, they are doubtless somewhat too high, though the error in the case of the water temperatures is probably slight.

It will be important for our future discussion to make a comparison of the water temperatures at Woods Hole and those at the United States Fisheries stations at Gloucester, Mass., and Boothbay, Me. For this purpose we have employed the records of only three years at each station, the same years (1905, 1906, 1907) being used in each case. Thus the figures here presented for Woods Hole necessarily differ somewhat from those given in the preceding table.

TABLE II.—MEAN WATER TEMPERATURES (NOON) AT BOOTHBAY, GLOUCESTER, AND WOODS HOLE FOR THE YEARS 1905, 1906, 1907.[a]

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Boothbay	[b] 33.5	[b] 30.3	32.2	37.8	44.1	51.8	58.5	61.0	56.0	48.7	42.4	37.0
Gloucester	36.1	32.7	35.7	41.4	48.2	56.6	63.1	63.1	59.8	53.2	45.8	39.7
Woods Hole	33.9	31.2	33.6	42.1	51.9	61.3	69.4	70.4	67.4	59.1	48.1	38.7

[a] Based upon records furnished by the superintendents of these stations.
[b] Based on two years only (1906, 1907).

From the foregoing figures the following facts may be gathered:

(1) That the mean water temperature for these three years was highest at Woods Hole (50.59°), next highest at Gloucester (47.95°), and lowest at Boothbay (44.44°).

(2) That these differences are at a maximum during the summer months, being reduced to a minimum or even reversed during the winter months. Thus the annual range of temperature is greater as we pass to the southward.

[a] Stated as 28° in the table. This was doubtless due to an error in the reading.

(3) For every month of the year the water temperatures at Gloucester are higher than those at Boothbay. On the other hand, during the months of December, January, February, and March the Woods Hole temperatures are lower than those reported from Gloucester, despite the more northerly location of the latter station. This is probably due to the fact that the water used at the Gloucester station is in more immediate connection with the great reservoir of ocean water, which responds more slowly to the winter cold. Moreover, a rapid intermingling of the two is effected by the tides, which have a far greater amplitude at Gloucester than at Woods Hole.[a]

(4) During the months of May to November, inclusive, the water temperatures at Woods Hole are much higher than those of either of the more northerly stations, while the mean difference between Woods Hole and Gloucester for July, August, and September (7.1°) is over twice as great as that between Gloucester and Boothbay (3.5°).[b]

This last feature of the comparison is the most important of all for our present purposes. The difference in latitude between Woods Hole and Gloucester is about 1° 7′, while that between Gloucester and Boothbay is about 1° 12′. Nevertheless, the difference in water temperature between those two stations, which are separated by the peninsula of Cape Cod, is twice as great during the three months of the year when the water is warmest as that between the two stations lying to the north of Cape Cod, even though the latter are divided by a greater interval of latitude. While the waters whose temperatures are here recorded may not be entirely representative of the neighboring sea areas, and while the number of years here comprised is small, the main points in our comparison are believed to be sufficiently well established. Let us now return to a consideration of the temperature conditions at Woods Hole.

Significant features of the local temperature conditions.—If we take the average of all the temperature determinations (surface and bottom) recorded on chart 211 for the 14 stations westward of Robinsons Hole, within and at the entrance to Vineyard Sound, we find the mean temperature of these waters, at practically the period of maximum temperature, to be 62.17.° At Woods Hole this temperature is exceeded during the entire period of the year between June 14 and October 6. If we consider only the figures for bottom temperature in this western area of the Sound (and these it is, in the main, which influence the bottom fauna), we find the mean to be 60.24, a temperature which is exceeded at Woods Hole, from June 3 to October 11. In Buzzards Bay, on the other hand, a temperature as low as this last was not once recorded during the August series of observations, though in one case it was found just beyond the mouth of the Bay (V). Bottom temperatures between 60° and 65° were, however, found throughout the lower third or fourth of the Bay, except near the western shore.

It thus appears that the summer conditions of temperature such as obtain in the vicinity of Woods Hole during the months of June, July, August, and September do not directly affect the southwestern third of Vineyard Sound and in only a limited degree the lower end of Buzzards Bay. It will be shown that this fact is of supreme importance for the understanding of certain features of distribution.

It might reasonably have been expected that the winter temperature of these outlying waters, adjacent to the open sea, would be considerably higher than that

[a] This is in full agreement with the explanation of the relatively high winter temperatures at Gloucester and Boothbay; independently offered by Superintendents Corliss and Hahn.

[b] This difference is likewise somewhat greater for October, and is practically the same for May.

elsewhere recorded within the region, owing to the conservative influence of the ocean in retaining the heat received during the summer. It would have given no surprise, therefore, to find the mean annual temperatures approximately the same throughout all these waters. Unfortunately we have no data for the coldest period of the winter. Reference to the temperature curves for the Woods Hole station shows that the water curve reaches its lowest level on February 19. It was planned, accordingly, to obtain a series of observations in Vineyard Sound and Buzzards Bay at about that date in 1908. It is a matter of much regret that no boat was available for this purpose until a month later, when the water temperature throughout the entire region had risen to nearly 37° F. At this time, as has already been pointed out (p. 44), a great uniformity in water temperature prevailed throughout the region explored, and the outlying waters, off Gay Head and Cuttyhunk, did not differ appreciably from those of the other portions of Vineyard Sound and Buzzards Bay. It will be recalled that in November there was likewise a large measure of uniformity, though at that time the outlying waters were somewhat warmer than the rapidly cooling waters of the upper half of the Bay. In the absence of further data it might be contended that at the time the November observations were made the inshore temperature was just passing the ocean temperature in its annual decline, while, on the other hand, it might be supposed that the March temperatures were taken at a time when the inshore temperature curve was again about to cross that for the ocean temperature. And indeed it is possible, that in the intervening months the latter did remain somewhat higher than the former.

But even on the impossible supposition that 36° F. represents the minimum temperature of these outlying waters,[a] this figure would be only about 7° higher than the lowest recorded elsewhere (i. e., the freezing point of sea water), whereas in summer the extremes of temperature varied as widely as 15°. Thus, in any case, the mean annual temperature of the bottom waters in the outlying portions of Vineyard Sound and Buzzards Bay is undoubtedly lower than that of the more inclosed areas to the northeast. For Vineyard Sound the mean bottom temperature of the stations lying to the seaward of Robinsons Hole, as based upon the four seasonal averages obtained by us, is 50.53°. The corresponding figure for the remainder of Vineyard Sound was found to be 53.31°. This difference, however, is entirely determined by the June and August results, so that for the summer months alone the difference would be about twice as great.

Another plain deduction from the foregoing figures is that the total annual range of temperature in these outlying waters is far less than in the more inclosed waters of the region. For the former the temperature range is probably about 30° F.; for the latter it may reach 45° or more.

The occurrence in summer of colder waters in the ocean immediately beyond the mouth of Vineyard Sound was pointed out by Verrill as long ago as 1871, and a few definite temperature figures were then presented by him. These last were also included in the chart accompanying the "Report on the Invertebrate Animals of Vineyard Sound." On September 9 the lowest figure recorded by Verrill was 57° F., which was the bottom temperature at a point several miles beyond Gay Head. Within the

[a] Rathbun (1887) in a chart (No. 17), giving temperatures taken during five years at the Vineyard Sound Lightship, off Sow and Pigs Reef, records figures as low as 29° and 30° during January and February. For most of the time during these months, moreover, the temperature remained below 35°. These were surface temperatures, it is true, but it is likely, as above stated, that the figures for surface and bottom are not far from equal in winter.

mouth of Vineyard Sound, on the same day, the surface temperature was 67° F. Temperatures were likewise taken west of No Mans Land and south of Narragansett Bay in 29 fathoms. These agree in being considerably lower than the temperatures known to occur at the same time in the more inclosed waters of the neighborhood. The present writers have found still more extreme conditions to prevail at certain points immediately to the east of Cape Cod. At Crab Ledge, a few miles to the east of Chatham (chart 223), at a mean depth of 17½ fathoms, two observations on August 12, 1909, gave a mean surface temperature of 65° F. and a mean bottom temperature of 47.2° F. These figures accord pretty well with some obtained at nearly the same point by Robert Platt, United States Navy, on September 14 and 15, 1877.[a] The latter found a mean surface temperature of 60.3° F. and a mean bottom temperature (28 fathoms) of 48.2° F. It is interesting to compare the figures obtained by us on August 10 and 12, 1909, for a series of points between Woods Hole and Crab Ledge. These are presented in the following table:

	Depth.	Surface temperature.	Bottom temperature.
Pollock Rip (just without Nantucket Sound)	5	63.0	62.0
Handkerchief Shoal (eastern end Nantucket Sound)	7	62.5	60.0
Cross Rip (middle of Nantucket Sound)	8¾	[a] 70.5	[a] 70.2
West Chop (eastern end Vineyard Sound)	12	71.0	69.5

[a] The mean of two determinations on different days.

Verrill explained the low temperatures of the outer waters by invoking the aid of "an offshoot of the arctic current," which he believed to pass westward into Long Island Sound. The question whether or not there is a definite southward (and westward) flowing current which affects this part of the coast has already been discussed briefly on another page. No conclusive answer to this question appears to be forthcoming at present. Undoubted, however, is the fact that during the summer months there lies a comparatively cold zone between the warm coastal water and the yet warmer Gulf Stream. This may, as has been suggested, merely represent the normal ocean water which would be proper to this latitude in the absence of the Gulf Stream. If this view be accepted, the higher temperature attained during the summer months by the waters of Buzzards Bay and of Nantucket and Vineyard Sounds is simply the result of their shallowness and comparative detachment from the great reservoir of ocean water outside, just as we know that salt marshes or shallow lagoons become even warmer than this during the summer months.

The question here suggests itself why the coastal waters north of Cape Cod, e. g., at Gloucester and at Boothbay, do not likewise become much warmer than they do during the summer months. We have seen (p. 49) that the relations between the temperatures at these points and those at Woods Hole are not such as are wholly explained by differences in latitude. It is highly probable that one factor in the case is the far greater depth of the waters north of Cape Cod, at slight distances from shore. For example, the 50-fathom line passes within from 5 to 10 (nautical) miles of Cape Ann and of many parts of the Maine coast; while at the nearest point it lies over 50

[a] These data were furnished us by the Superintendent of the Coast and Geodetic Survey.

miles from Marthas Vineyard. The tides, likewise, are of much greater amplitude north of Cape Cod, insuring a far more rapid intermingling of the coastal waters with those of the open sea. South of Cape Cod there is an extensive area of shoal water, much of which is pretty definitely bounded off from the open ocean. Reference has already been made to the occurrence of a net westerly tidal movement through Vineyard Sound. This implies, of course, that the latter derives much of its water from Nantucket Sound, a broad and on the whole very shallow area of sea, pretty well shut in by land and by shoals.

5. SALINITY.

Salinity or, more properly, density determinations were made along with those for temperature. The Sigsbee water cup was employed for obtaining samples from the bottom, while the surface water was merely drawn up in a pail. The salinometers employed were of the Hilgard pattern and were previously tested by the Bureau of Standards. Great care was taken to prevent the soiling of the stem by the hands, which was found to exert a marked effect upon the level reached by the instrument. A bottle of caustic soda solution, or a mixture of sulphuric acid and potassium bichromate, was kept at hand, and used from time to time for cleaning the stem. It was found more practicable to read from the summit of the meniscus, or cone of fluid surrounding the salinometer stem, than to read from the actual water level. The value of the meniscus in terms of the scale was later determined. Since the temperature of the water is an all important factor in determining its specific gravity, as referred to distilled water at maximum density, careful record was kept of the water temperature at the time of taking the reading for density. Knowing these two factors, reduction was easily accomplished by the aid of a table furnished by the Bureau of Standards.[a]

The figures, as presented, represent the specific gravities which would have been obtained had the water samples in all cases been at a temperature of 15° C. Thus each figure represents the relative weight of a given sample at 15° C. compared with an equal volume of distilled water at 4° C. The density of a solution depends, of course, upon two factors, its temperature and its concentration. Having eliminated all differences due to the former factor, the figures here given represent the concentration, i. e., the salinity of the water.

The density readings here recorded were in nearly all cases made aboard ship. More precise determinations would of course have been possible if the water samples had been bottled and brought back to the laboratory where the ship's motion would not have disturbed the observations.[b] And our results would have been still more precise had we resorted to the method of titration with nitrate of silver, as employed in recent hydrographic studies.[c] The latter method has, however, been used by us as a check upon our specific gravity determinations, and the results of the two accord so well on the whole (see p. 54) that the figures here presented are probably exact enough to meet the demands of the present work. Our figures for density are recorded to the fourth decimal place. From comparison with the chlorine tests it seems likely that in

[a] Various tables of this sort have been published; e. g., Libbey, 1891, p. 397; Tanner, 1897, p. 337.

[b] In five cases, in which this was done, and the results of the two independent determinations were compared, a mean difference of 0.00024 was found; i. e., the error affected only the fourth decimal place, or last one considered in making the reading.

[c] See Pettersson, 1894, p. 296; also account of International Conference for the Exploration of the Sea, in Journal of the Marine Biological Association, vol. VI, pp. 101-104.

some cases they are accurate only to the third decimal place. Those familiar with recent hydrographic studies will perhaps regard such figures as too rough approximations to have any scientific value. This would doubtless be true if we had to do with wide expanses of the sea, containing fairly permanent currents or strata of water, the limits of which could only be ascertained by determining slight differences of salinity. But in the inclosed bays and sounds of our region the continual intermixture of the waters resulting from tides and winds would render unlikely any constant stratification on the basis of salinity, and it is certain that rapid variations occur within the same area. As was the case with the temperature records already discussed, a series of determinations having no reference to the phase of the tide are open to rather serious objections. But it would be practically impossible to make such a series simultaneously throughout so large an area, and almost equally difficult to make each of them at a corresponding phase of the tide. For these reasons, therefore, only the larger differences of water density, such as are indicated by figures in the third decimal place, seem to be of interest in attempting any correlation between this factor and the distribution of our local marine animals and plants. And it will be found later that, so far as our dredging records are concerned, even the greatest extremes of salinity which are recorded by us have little or no effect in limiting the distribution of most of the species. This statement, of course, is only intended to apply to the fauna taken by the dredge. Great numbers of littoral or shallow-water organisms, here as elsewhere, obviously thrive best in brackish water or at least in somewhat diluted sea water. The salt marshes and the estuaries, indeed, are largely populated by a fauna of their own.

The figures for density are given in the same tables (1–8) as those for temperature. From the density figures those for salinity proper, or percentage of salts, may readily be obtained from the table offered by Pettersson (1894, p. 298). The following equivalents have been computed for such degrees of density as are to be found in Buzzards Bay and Vineyard Sound. They represent the percentages of salt by weight in a given quantity of sea water:

Density.	Salinity.	Density.	Salinity.
1.0210	2.84	1.0230	3.09
1.0215	2.91	1.0235	3.16
1.0220	2.98	1.0240	3.23
1.0225	3.03	1.0245	3.29

The differences of salinity, in relation to locality and season, are represented upon charts 215 to 218. Several facts of importance are to be derived from these tables and charts.

(1) Even the highest figure recorded here (1.0244) is considerably lower than that found throughout the north Atlantic at great distances from land, where a specific gravity of 1.0270 to 1.0280 prevails.

(2) The greatest extremes to be found among our determinations are 1.0212 and 1.0244, representing a difference of about 15 per cent in salinity.

(3) The average surface density (1.02337) is lower than the average density at the bottom (1.02349). This difference is more marked in the Bay than in the Sound. It is

manifested in six of the eight pairs of contrasted figures, the June figures (both for the Bay and Sound) being exceptions.

(4) The average density for Buzzards Bay (1.02314[a]) is lower than that for Vineyard Sound (1.02372) and is particularly low at the head of the Bay. This condition is readily understood by reference to the estuaries which discharge into it.

(5) Certain seasonal differences appear which are, perhaps, of questionable significance. In Vineyard Sound the density figures for the seasons may be arranged in the following order:

June	1.02339
March	1.02358
August	1.02387
November	1.02403

For Buzzards Bay the figures can not be given for the entire area, since in March only six stations, nearly all of them in the upper half, were visited. Taking the figures for these same six stations for the four months we find the following order to obtain:

March	1.02266
June	1.02273
November	1.02299
August	1.02327

The figures for the different seasons were obtained at intervals of about three months and by two different observers. Differences due to "personal equation" have thus perhaps played a part in the results. And even if that source of error were eliminated, it is quite likely that the figures for the same month in different years would not agree at all exactly. In November, 1908, eight of the determinations of the preceding November were repeated. The average difference between the earlier and later figures was 4 in the fourth decimal place, i. e., a quantity in excess of some of the seasonal differences appearing in the foregoing tables.

In order to compare the results of hydrometer readings with those obtained by titration for chlorine, 17 water samples were subjected to both tests.[b] The chlorine determination in each case was compared with the value, computed from Pettersson's table, for water of the specific gravity recorded. It was found that the actual and the expected values differed on the average by 1.5 per cent. On the assumption that the figures for the titrations were absolutely correct, which is scarcely allowable, this discrepancy implies an average error in the salinometer readings amounting to a little over 3 in the fourth decimal place. We have thus, in any case, some measure of the accuracy of the specific gravity determinations here recorded. As already stated, the fourth figure is not entirely trustworthy. It must be remembered, however, that local differences have been pointed out within our region equal to about ten times the amount of this average error.

Seven water samples obtained by us in August, 1909, at points within Nantucket Sound and beyond its eastern end, yielded specific gravities varying only from 1.0237 to 1.0239. These figures are close to, but slightly lower than, those found in Vineyard Sound during the same month two years previously.

[a] This figure is somewhat too low, since only the upper half of the Bay was represented in the March series. Here, as stated, the density is particularly low.

[b] These titrations were for the most part made by Dr. W. M. Clark, then a scientific assistant at the Woods Hole laboratory.